Student work

Which Material is best for Constructing Cooking Pans? (Lab Report)

Research Question: Which of the following three materials heats water best and is hence the best for constructing cooking pans?

1. Glass
2. Aluminium
3. Copper

Variables:

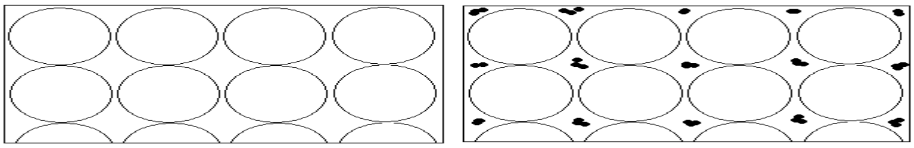
- Independent/Experimental Variable(s)
  - Material used
  - Time taken to heat substance inside each materials
- Dependant Variable(s)
  - Speed at which material conducts heat
  - Temperature of substance inside material during the experiment
- Controlled Variable(s)
  - Amount of water heated inside different materials
  - Mass/amount of material used
  - Amount of time material is heated
  - Starting Temperature of water that will be heated[1].

Background Information:
This lab focuses around the three materials transferring heat from a heat source to a substance inside them. Therefore, before we begin the experiment, it is important to know the background information regarding the transfer of heat between these three materials.

In general, metals are good conductors[2] of heat and are much better conductors of heat than non-metals; which are generally better insulators[3] of heat. This means that ideally, copper and aluminium – which are metals, should heat water faster than glass, which is a non-metal and thus will be weaker at heat transfer or conduction. Glass is a good insulator because it usually has air inside it and air holds heat and prevents it from being conducted.

The reason metals are better conductors than non-metals are because metals have *free electrons*[4]. These free electrons heat the metal and enable the transfer of heat to be swifter than in non-metals. The diagrams below compare non-metals to metals and show how metals have free electrons that enable them to conduct heat better. The black dots represent free electrons:

[1] The starting temperature will be the room temperature at the time and can only be influenced by the atmospheric temperature at the time or day of experiment.
[2] Conduction: "the transfer of heat from one body to another" (Bell), good conductors conduct heat well.
[3] Insulation: the opposite of conduction. Good insulators are bad conductors.
[4] *Free Electrons* are electrons that are not solid, formed particles of a metal and vibrate when the material is heated.



Non-Metal **Metal**

What makes metals conduct heat faster than non-metals is the fact that these free electrons vibrate and heat all parts of the metal at a much faster speed than non-metals.

You can tell how well a material or substance conducts heat by its *Specific Heat Holding Capacity*[5]. Generally, the best conductors have a very low heat holding capacity because this implies that they cannot insulate heat well and thus can conduct it well. We can tell which out of these three materials is likely to be the best or worst heat conductor by examining their heat holding capacities. The following table displays the heat holding capacities of all three materials:

Material	**Heat Holding Capacity**
Glass	9.4J/gºC
Aluminium	8.8J/gºC
Copper	3.8J/gºC

From the table above we can see that copper has the lowest heat capacity which means that it is likely to conduct heat better than all the other materials. Aluminium is likely to be the second best conductor because it has the second lowest heat capacity. Glass is likely to be the best insulator of heat out of these materials because it has the highest heat holding capacity, which means that it can hold heat the best and is not an efficient conductor of heat.

Hypothesis: I predict that copper will be the best conductor of heat out of these three materials and subsequently the best material for constructing cooking pans because of two reasons:

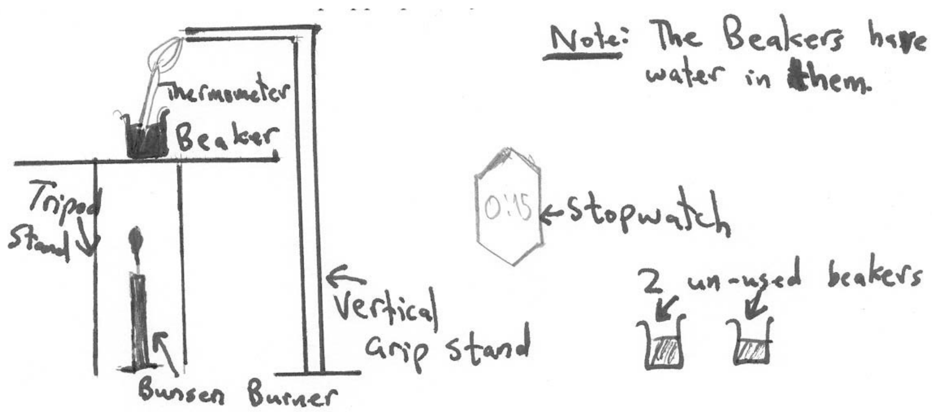
1. it is a metal and metals are good conductors of heat
2. It has the lowest heat holding capacity out of all three materials, which means that it is the least capable of holding heat and the most capable of conducting heat.

[5] The Heat Holding Capacity is how well the substance can hold heat or how well it can insulate.

Apparatus:

- 1 mat[6]
- 1 tripod stand
- 1 grill
- 1 glass beaker – 31.2g in mass
- 1 copper beaker – 40.0g in mass
- 1 aluminium beaker – 27.9g in mass
- 1 Bunsen burner
- 3 thermometers[7]
- 4 pairs of safety goggles
- 1 vertical grip stand, to grip the thermometers.
- Gas source
- 1 box of matches
- 1 stopwatch

The apparatus looks as follows when set up appropriately:



Method/Methodology:

1. Collect the apparatus listed above.
2. Put 70ml of water in each of the three beakers. The amount of water is controlled at 70 ml, to make for a fair test and to ensure that no material has extra or less water to heat.
3. Put 1 thermometer in each beaker
4. Measure and record starting temperature, which should be the same as room temperature. This also means that the starting temperature for all materials should be the same. This will not be hard, since room temperature does not vary.
5. Set up apparatus, excluding the 3 beakers
6. Set one of the beakers on the tripod stand
7. Heat the beaker (and the water inside it) using the Bunsen burner.
8. Time the heating of the water and beaker, using the stopwatch, and record temperature after every 30 seconds
9. Repeat this until 5 minutes have passed
10. Repeat 6-10 for the remaining 2 beakers
11. Record data and plot graph.

[6] Made of cork, to prevent any safety hazards when heating

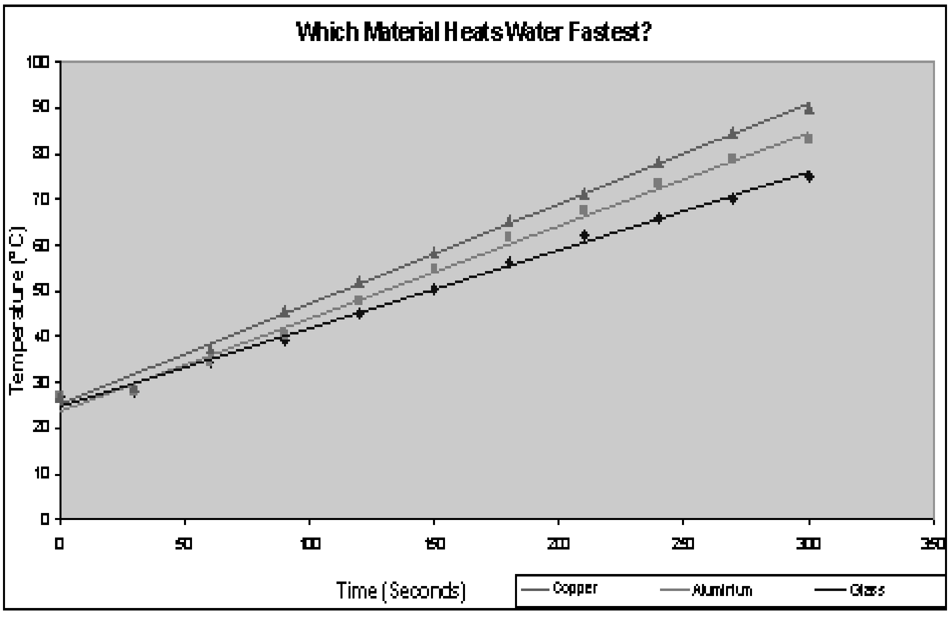
[7] So that each thermometer can be used for a different material. This ensures that each thermometer is at the same temperature when the experiment begins. This measure provides for a fair test.

Data Collection:

The following table displays and compares the recorded temperature of each material during heating:

Time (Seconds)	Temperature of Glass Beaker (ºC)	Temperature of Aluminium Beaker (ºC)	Temperature of Copper Beaker (ºC)
0	27.0	27.0	27.0
30	28.0	28.0	29.0
60	34.0	34.0	37.5
90	39.0	40.5	45.5
120	45.0	47.5	52.0
150	50.5	55.0	58.5
180	56.5	61.5	65.5
210	62.0	67.5	71.5
240	66.0	73.5	78.0
270	70.5	79.0	84.5
300	75.0	83.0	90.0

Data Analysis: The following graph displays the data in the table above in a visual manner.



The graph above clearly shows that copper heat water fastest out of the three materials. The linear trend lines on the graph shows that although the water in all materials starts off at room temperature, it ends up at a different temperature after 5 minutes are up.
The graph clearly shows that the non-metal glass is the poorest conductor of heat, whilst the metals are better at heating water. We can elaborate on this point by finding out how much energy it took for each material to conduct heat. Ideally, if a material is a good conductor, it will require less energy to conduct heat through it and if it is a good insulator, it will take

more energy to conduct heat through it. This can also be used as a way to check the general trend of our data. For example, if aluminium requires the least energy to conduct heat then we know that our data has been incorrectly recorded or our experiment has been incorrectly executed. Ideally, copper should require the least energy to conduct heat (seeing as it is the bets conductor of heat, according to the graph above).

To calculate how much energy each material requires to conduct heat we use the formula:

Energy needed = mass x heat holding capacity of material x temperature change

The mass of each material was determined prior to executing this experiment. Similarly, the heat holding capacity of each material was investigated prior to this experiment being executed. The temperature change represents the difference between the starting temperature and the final temperature of the water inside each beaker. It can be found by the following method:

Temperature change = final temperature – starting temperature

The mass of each material is measured in grams and therefore the heat holding capacity of each material is notated in J/gºC. The energy required to heat material is as follows:

Glass:

Temperature change = final temperature – starting temperature
Temperature change = 75 – 27
Temperature Change = 48

Energy needed = mass x heat holding capacity of material x temperature change
Energy needed = 31.2 x 9.4 x 48
Energy needed = 14077.44 Joules

Aluminium:

Temperature change = final temperature – starting temperature
Temperature change = 83-27
Temperature Change = 56

Energy needed = mass × heat holding capacity of material × temperature change
Energy needed = 27.9 x 8.8 x 56
Energy needed = 13650.56 Joules

Copper:

Temperature change = final temperature – starting temperature
Temperature change = 90-27
Temperature Change = 63

Energy needed = mass × heat holding capacity of material × temperature change
Energy needed = 40.0 x 3.8 x 63
Energy needed = 9576 Joules

The following table compares the energy required to conduct heat through each of these materials in this experiment:

Material	**Energy Required to Conduct Heat (Joules)**
Glass	14077.44
Aluminium	13650.56
Copper	9576

We can see from the table above that it took copper the least amount of energy to conduct heat. This verifies our results and thus proves that copper is indeed the best heat conductor out of these three materials.

We can elaborate even more on our results by finding out how much energy it took the water inside each material to heat up. Unlike the previous analysis of the energy needed for each specific material to conduct heat, this analysis focuses on how much energy the water inside each material used. This means that we will be calculating the energy used by the water, as opposed to the material. Ideally, the better the conductor, the more energy it will use to heat the water inside it. This is because the water inside a conductive material is heated more and this causes a larger temperature change which leads to more energy being used.

Let us now verify our data once more using the calculations for the amount of energy used by the water inside each material.

For our experiment, to calculate how much energy the water inside each material used, we use the following formula:

Energy used = mass of water x heat holding capacity of water x temperature change

The material in this case is water, since it is what is being heated. The mass of the material is 70g, because we determined this at the beginning of our experiment when we stated that 70ml of water would be used inside each container. 70ml converts to 70g in mass because:

1g = 1ml

The heat holding capacity of the material (water) is 4.2J/gºC. This means that it takes 4.2 Joules to heat 1 gram of water so that it alters its temperature by 1ºC.

The temperature change represents the difference between the starting temperature and the final temperature of the water inside each beaker. It can be found by the following method:

Temperature change = final temperature – starting temperature

The following are the calculations of the energy required to heat the water inside each of the beakers:

<u>Glass:</u>

Temperature change = final temperature – starting temperature
Temperature change = 75 – 27
Temperature Change = 48
Energy used = mass x heat holding capacity of material x temperature change
Energy used = 70 x 4.2 x 48
Energy used = 14112 Joules

<u>Aluminium:</u>

Temperature change = final temperature – starting temperature
Temperature change = 83-27
Temperature Change = 56

Energy used = mass x heat holding capacity of material x temperature change
Energy used = 70 x 4.2 x 56
Energy needed = 16464 Joules

<u>Copper:</u>

Temperature change = final temperature – starting temperature
Temperature change = 90-27
Temperature Change = 63

Energy used = mass x heat holding capacity of material x temperature change
Energy used = 70 x 4.2 x 63
Energy needed = 18522 Joules

The following table compares the energy required to heat the water inside each of the materials:

Material	Energy Required to Heat Water (Joules)
Glass	14122
Aluminium	16464
Copper	18522

We can see from the table above the water inside the copper container used the most energy to be heated. This verifies our results once again and proves that copper is indeed the best heat conductor out of these three materials because the water inside it heated the most and used the most energy to heat up.

Having verified our data, we can now predict which material would have boiled the water first and whether or not the trend of data in our graph stays the same as the temperature increases by finding the linear equation representing the data for each material. For this we must first determine the *gradient of our data*[8]. This can be done by taking two co-ordinates from the graph or table and labelling the first co-ordinate as (x1,y1) and the second co-ordinate as (x2,y2). For example, if the temperature of the water in the glass beaker is 28ºC after 30 seconds, since the time taken is the independent variable[9] and the temperature of the substance inside each material is the dependant variable[10], the co-ordinates of this point will be (30,28). The gradient of a line of data can be calculated as follows:

$$Gradient = (y2-y1) / (x2-x1)$$

[8] The rate at which our data (the temperature of the water inside each material) increases.
[9] X=independent variable
[10] Y=dependant variable

To find a linear equation of a set of data you also need the *y-intercept of the data*[11]. Since our data is measured from when the temperature is 27ºC, the y-intercept of all the data will be 27. Below is a calculation of the slope of data of each material along with the formation of the equation of the data of each material. I have taken the co-ordinates of the starting and final temperature of the water in each substance since these are the only two co-ordinates that are certain to be consistent with the trend of data in the case of each material.

<u>Glass:</u>
Co-ordinate 1 (x1,y1) = (0,27)
Co-ordinate 2 (x2,y2) = (300,75)

gradient = (y2-y1) / (x2-x1)
gradient= (75-27) / (300-0)
gradient= 48 / 300
gradient = 0.16 or 4/25

Equation : y=4/25x+27 [12]

<u>Aluminium:</u>
Co-ordinate 1 (x1,y1) = (0,27)
Co-ordinate 2 (x2,y2) = (300,83)

gradient= (y2-y1) / (x2-x1)
gradient = (83-27) / (300-0)
gradient = 56 / 300
gradient = 0.187 or 14/75

Equation : y=14/75x+27 [13]

<u>Copper:</u>
Co-ordinate 1 (x1,y1) = (0,27)
Co-ordinate 2 (x2,y2) = (300,90)

gradient= (y2-y1) / (x2-x1)
gradient= (90-27) / (300-0)
gradient = 63 / 300
gradient = 0.21 or 21/100

Equation : y=21/100x+27 [14]

We can now use these equations to find which material will boil water fastest. Since we want to find the **time** at a certain temperature we will solve for x. The following is the time it will take for the water in each material to boil (water boils at 100ºC).

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[11] The point at which the data crosses the y-axis, or in this case, the point at which we being our experiment.
[12] Y=temperature of substance inside material, X=time (Seconds)
[13] Y=temperature of substance inside material, X=time (Seconds)
[14] Y=temperature of substance inside material, X=time (Seconds)

Glass:
Y = 100 [15]

$$Y=4/25x+27$$
$$100=4/25x+27$$
$$100-27=4/25x$$
$$73=4/25x$$
$$73=0.16x$$ [16]
$$73/0.16=x$$
$$456.25=x$$

Time taken to boil water: 456 seconds, or 7 minutes and 36 seconds

Aluminium:
Y = 100

$$y=14/75x+27$$
$$100=14/75x+27$$
$$100-27=14/75x$$
$$73=14/75x$$
$$73=0.187x$$ [17]
$$73/0.187=x$$
$$390.397=x$$

Time taken to boil water: 390 seconds, or 6 minutes and 30 seconds

Copper:
Y = 100

$$Y=21/100x+27$$
$$100=21/100x+27$$
$$100-27=21/100x$$
$$73=21/100x$$
$$73=0.21x$$ [18]
$$73/0.21=x$$
$$347.62=x$$

Time taken to boil water: 348 seconds, or 5 minutes and 48 seconds

The following table shows how long it would take each material to boil the water within it:

Material	**Time taken to boil water (seconds)**
Glass	456
Aluminium	390
Copper	348

From the table above, we can tell that copper will be the fastest material to boil water. Since most cooking evolves around boiling water, it is now safe to say that copper is the best material out of the three above to use for construction of cooking pans.

[15] We know the value of Y as being 100 because this is the temperature at which water boils.
[16] 4/25=0.16
[17] 14/75=0.187
[18] 21/100=0.21

Conclusion and Evaluation: My results from this experiment show that my hypothesis was validated, because copper turned out to be the best conductor of heat and thus the best material for use in constructing cooking pots and pans. Further calculations showed us that as the temperature increases, it takes copper the least amount of time to boil water; 348 seconds, in comparison to 390 and 456 for aluminium and glass respectively. Clearly, copper conducts heat much better than the other two materials, with aluminium being the second best conductor of heat and glass being the worst.

The possible sources of error in my lab were as follows:

- I used beakers of different masses. This did not have any impact on my results and they turned out to be as expected. However, the fact that the copper beaker was heavier than the aluminium beaker means that it was thicker and this influenced the way heat was conducted through this material.
- We did not cover the beakers when heating them and heat could have escaped from the top and slowed down the heating process of the water in each beaker.
- We only measured the temperature increase for 5 minutes. It is possible that copper could have slowed down heating water as the temperature neared 100ºC and it is possible that glass could have continued heating at the same rate. Although this is unlikely, it could have happened and we did not examine its effects.

The limitations of my lab were as follows:

- We only had three materials with which to conduct our experiment. Had we had more, we could have made our conclusion based on a wide variety of data.
- We had rather small containers. If we had larger containers we could have examined a larger temperature change and examined a greater level of heat conduction.
- We were not able to obtain containers of the same mass. We were only able to use the containers available and this limited our data from being fully accurate and it limited our test from being fully fair.

If I were to do this lab again I would:

- Use beakers of the same mass (or try to at least; depending on whether or not the materials are available in the same mass), to prevent any distortion of the correct results.
- Cover the beakers so as to prevent heat loss.
- Measure how long it takes the beakers to heat water to a certain temperature as opposed to simply how hot the water gets in a certain amount of time. This will give the same conclusion but it makes it easier to analyse results.
- Use many more materials as opposed to just three. This would make for a more balanced conclusion, which will have taken into account the heat holding capacities of many materials.

Questions for Further Research: For further research I would suggest that we examine other metals and how fast they heat water. Perhaps we could use another liquid instead of water; for example, oil. This is because oil is used in cooking as well, and it would be useful to examine how each material heats oil, because oil has a different boiling point to water[19].

Works Cited

Bell, Kenneth J. "Heat Conduction." Macmillan Encyclopaedia of Chemistry. 1997 ed.

Johnson, Keith. Physics for You. Stanley Thornes (Publishers) Limited; Cheltenham, 1996.

[19] The boiling point of oil is 70ºC as compared to the boiling point of water; 100ºC.